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Simulation of the Interaction Between Airdrop Platforms and Aircraft Rollers

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

All airdrop loads must be certified as not exceeding the maximum aircraft roller loads. This certification is presently accomplished by a series of tests which are numerous and complex. This report looks at the possibility of replacing this test procedure with a numerical simulation. Two simulations are examined; a straightforward deterministic structural simulation and a structural simulation that includes the imperfections in the system in a statistical manner. The imperfections in the system are large enough to make the deterministic structural model

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20. Abstract (cont'd)

inadequate, and insufficient data are available to make an accurate statistical model of the imperfections. As a result, it was not possible to develop a complete model to carry out the roller load simulation, although only the imperfection model is needed for completion of the statistical simulation. The statistical model was used to demonstrate that the use of very flexible rollers would reduce the importance of the imperfections in the system.

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SIMULATION OF THE INTERACTION BETWEEN AIRDROP PLATFORMS AND AIRCRAFT ROLLERS

INTRODUCTION

The C–141 aircraft is equipped with rollers on which airdrop platform loads ride during loading, flight, and discharge. The aircraft design places limits on the load that these rollers are allowed to support; a single roller load must not exceed 1580 pounds* and the total load on any row of four rollers across the aircraft must not exceed 2500 pounds. Before any airdrop load can be flown in the aircraft it must be certified that these 1g roller load limits are not exceeded. This certification is currently accomplished by a series of tests on the roller load test facility at NLABS. These tests require the delivery of the airdrop load to the test facility at NLABS, the rigging of the load on the platform, and the subsequent testing which requires 20 repetitions to obtain statistical significance. Because of the complex nature of these tests, it was suggested that the tests might be replaced with a mathematical simulation. Such a simulation would have to be implemented on a digital computer and would include a model of the aircraft roller system, a platform model, a model of the load to be airdropped and the interaction of these separate structural models. In this report we describe some work on the development of such a model. This initial work is restricted to modeling the roller system and platform and their interaction under load. The load used here is a dead weight load and no attempt is made to model real airdrop loads. Two models of the interaction are treated: a deterministic model in which the rollers and platforms are always in contact and a statistical model in which the contact between the rollers and platform is described statistically. In the case of the statistical interaction model we examine the influence of roller stiffness on the distribution of load among the rollers. Earlier work on the structural modeling of airdrop platforms is reported in reference 1.

DETERMINISTIC MODEL

Initial considerations of the modeling of the aircraft roller system, the airdrop platform and their interaction suggested a rather straightforward linear structural model and here we describe this model, give some computer results and compare these results with some test results.

Model Description

Platform Model

The majority of the structural model is concerned with the air delivery platform and here we consider only the Type II Modular platform. This platform is described in detail along with its rail system in US Army NLABS drawings 11–1–317, 11–1–318, 11–1–319,

*The drawings, nomenclature, and computer programs describing the Type II airdrop platforms use U.S. Customary units. Since this report depends on these data, these units are used here also. Table 3 gives the conversion between U.S. Customary and SI units.

[1]W. S. Chang and E. A. Ripperger; Stress and Deflection in Type II and Type IV Airdrop Platforms; US Army Natick Labs Technical Report 70–56–AD; Dec 1969. (AD–711556)

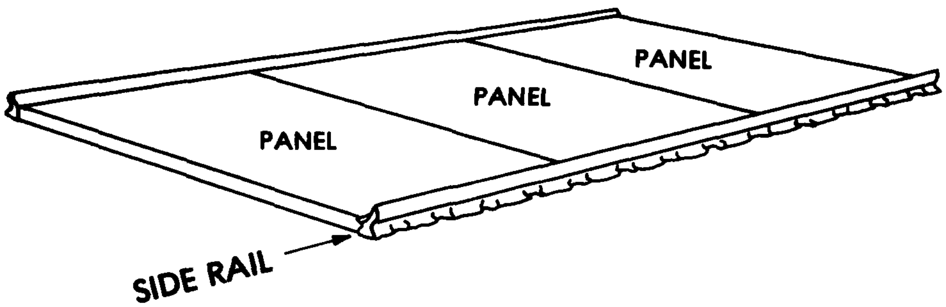
11–1–320 and 11–1–321. As illustrated in Figure 1, these platforms are aluminum skin-balsa core sandwich panels with beams on the edges. The longitudinal beams, those along the short sides, have provisions for the attachment of the side rails, and these rails are included in the model. The lateral beams, those along the long sides, serve as panel close-outs. The four-foot panel modules can be joined to form various length platforms from eight to twenty-eight feet in four-foot increments.

The computer structural model is constructed using the NASTRAN finite element program, and in Appendix A a FORTRAN program to generate a NASTRAN Bulk Data Deck which embodies this model is presented. This FORTRAN program includes documentation and model data and requires only the input of an integer code to specify the length of the platform for which the model is desired. In the following we give a general description of this model. The basic layout of the model for the eight-foot platform in terms of the coordinates, node locations and element types is shown in Figure 2. As shown in this figure, the origin of coordinates is located laterally at the center of the platform and longitudinally along the first row of rollers. This location is common for all platform lengths, and since the platforms are located relative to the rollers by the aircraft restraint system, the hangover on the end of the platform varies with the platform length as do the x coordinates of the node locations. The nodal pattern is generally regular with nodes located longitudinally at roller positions and laterally at roller positions plus three other positions chosen to give reasonable plate element goemetries. This regular pattern of node placement is not used at the platform edges nor at the junctions of panels where the regular pattern would have resulted in unreasonably narrow elements. In these cases the nodes (nodes 36, 37, ..., 42 for example) are placed along the edges of the balsa core-sandwich panel; in fact the lines of nodes along the panel edges define the edge of the balsa core. These lines of nodes do not coincide with the centroids of the beams but are offset. As a result, this line of nodes is also offset from the rollers, along the platform edges which contact the edge beams. The center line of the roller is outboard of this line of nodes.

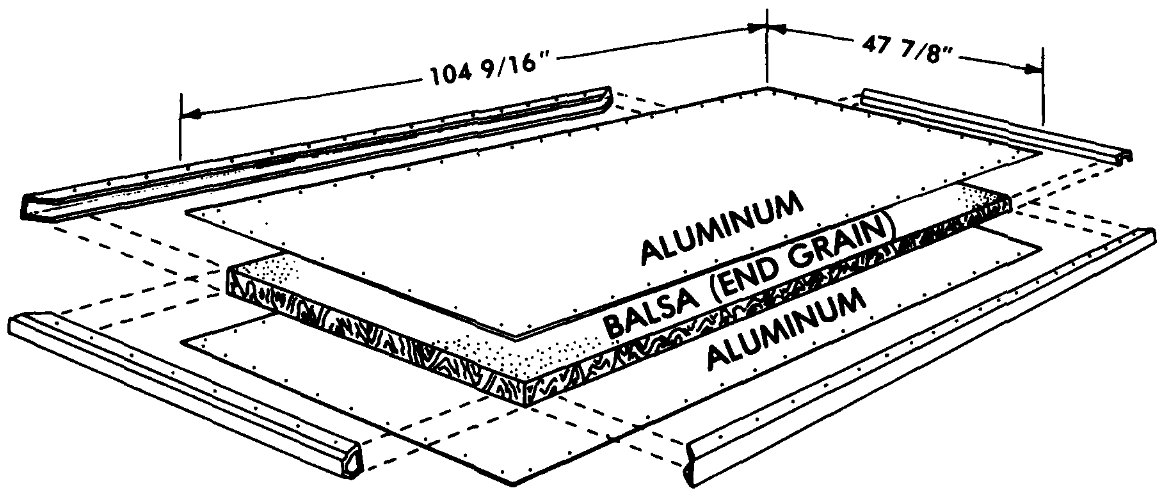
At the junctures of the panels we have two rows of closely spaced nodes with no intervening plate elements. For example there are no plate elements between the row containing nodes 36, 37, ..., 42 and the row containing nodes 43, 44, ..., 49. The three inches between these two rows of nodes is the space occupied by the lateral edge beams in the actual platform. The two rows are needed because the panels are not joined with complete displacement continuity as would be the case if a single row of nodes was used along the module juncture. The panels are joined in the model by equating the corresponding displacements and rotations at the edge nodes and only the bending rotations at the interior nodes in each of the two rows. The beams are modeled with the NASTRAN beam element, CBAR, which requires six degrees of freedom at each of its nodes so all nodes to which beams are joining retain the usual six degrees of freedom. The platform is modeled with the plate bending element CQDPLT, which requires only three degrees of freedom per node, the transverse bending displacement and two bending rotations, so, for all nodes to which only plate elements are joined, only these degrees of freedom are retained.

Roller Model

The roller system in the C–141 aircraft consists of four rows of rollers laterally across the cargo compartment and these rows are spaced every ten inches longitudinally along the



Assembled 12 foot platform
with side rails



Four foot platform panel

Figure 1. Type II modular air-delivery platform

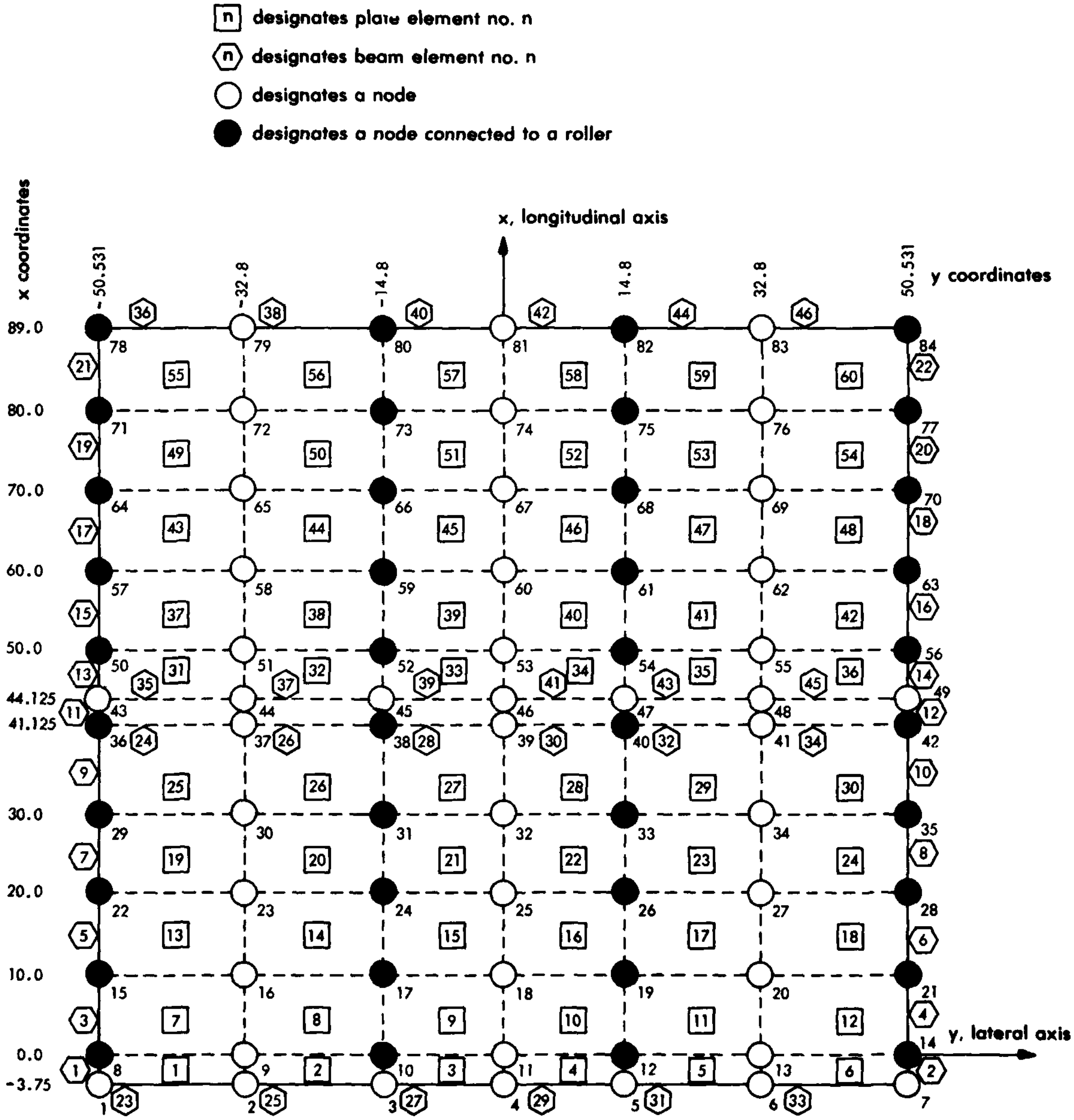


Figure 2. Layout of the element grid for the platform model

aircraft. The roller which can be seen in Figure 3 is a cylinder 3-3/4 inches long with a diameter of 1–7/8 inches.

The roller is modeled as a linear one-dimensional spring and the actual NASTRAN element used is CELAS2 which joins a specified node to ground with a spring of specified stiffness. This roller stiffness was determined from the test of the roller setting on a rigid platform as shown in Figure 3. As a result, the model contains no influence of aircraft floor stiffness. This was done for at least two reasons: data on aircraft floor stiffness were not readily available, and in the roller test facility the rollers rest on rather rigid supports and the model will be validated against test data from the roller test facility. The model thus constructed simulates the roller test facility not the aircraft floor. Once the aircraft floor stiffness is available, it is a simple matter to change the model to simulate the floor. In fact, it would be relatively simple to have the spring stiffness nonuniform with respect to location on the platform.

Platform-Roller Interaction

The interaction between the platform and the roller system is modeled by permanent contact between the platform and the rollers. Since, in general, we have a platform node at every roller location, this model is accomplished by connecting the platform nodes to ground through a spring. This is essentially enforcing continuity between the transverse displacement of the platform node and the extension of the spring connected to ground. There are two situations where the connection is not so straightforward: at all the rollers along the panel edges, and at the juncture of the platform modules. In the first case the rollers are offset from the nodes because the nodes are positioned to define the edge of the balsa core as discussed above. In the second case the nodes were offset from the rollers to avoid unreasonably narrow plate elements. The connection of the roller springs to the platform nodes in the case of offset rollers is accomplished by expressing the platform displacement over the roller position in terms of the nodal displacements. Referring to notation in Figure 4, the continuity between roller spring and platform is expressed as

$$W_s = W_n + \bar{y}\phi_x - \bar{x}\phi_y$$

This can be converted to a force relationship by multiplying by the roller spring stiffness K to give

$$KW_s = KW_n + \bar{y}K\phi_x - \bar{x}K\phi_y$$

The NASTRAN code makes it convenient to connect the node associated with an offset roller to ground with three springs having stiffnesses K, $\bar{y}$K, and $\bar{x}$K and associated with the W, ϕ_x, and ϕ_y degrees of freedom, respectively.

Data Generation Program

The data generation program presented as Appendix A is set up to generate a bulk data deck for NASTRAN which embodies the above-described models. The program requires input of a control parameter which indicates the platform length to be modeled and some data specifying the load which is peculiar to the load being modeled here and described subsequently.

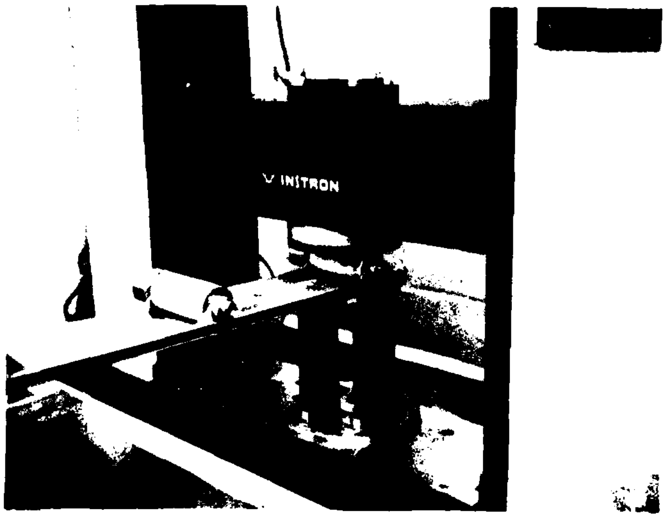


Figure 3. Test to determine roller stiffness

W_n = DISPLACEMENT OF NODE n
W_s = DISPLACEMENT OF ROLLER SPRING
$\phi x, \phi y$ = ROTATIONS ABOUT x AND y AXES AT NODE n
$\overline{x}, \overline{y}$ = x AND y OFFSETS BETWEEN NODE AND ROLLER

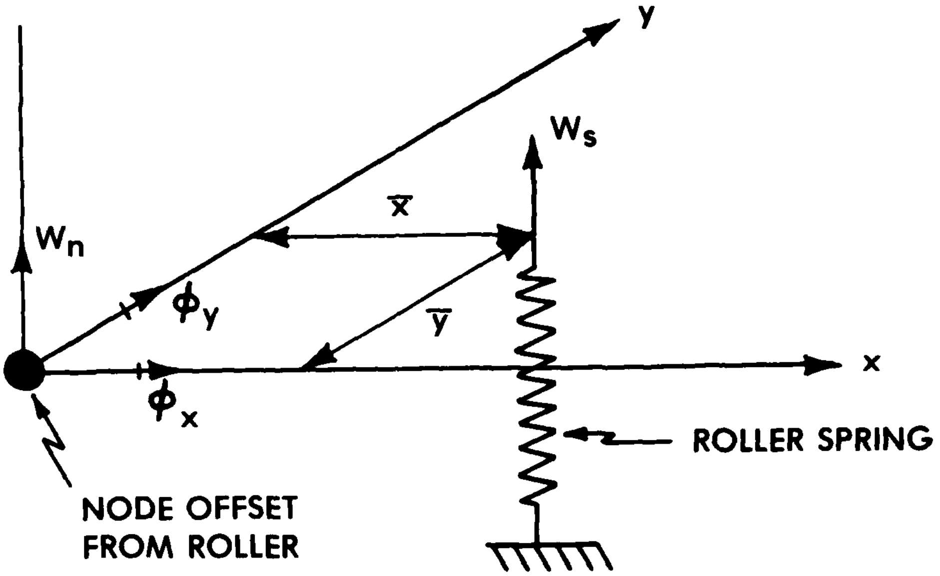


Figure 4. Nomenclature for modeling the connection of offset rollers

For any other load distribution this part of the data generation program would need to be changed. Since the platforms and rollers are constant, all the data relative to these models is in data contained in the program and identified there. This data includes the platform, beam and roller stiffness properties, and node location properties.

Model Performance

Once we have a NASTRAN bulk data deck, it is a relatively simple procedure to obtain a solution and thus the roller load predictions of the model. What is needed is a NASTRAN executive control deck and case control deck which are given in Appendix B along with a UNIVAC EXEC 8 run stream to execute the entire program, including generation of the bulk data deck, on the UNIVAC 1106 computer.

Having the model solution, it is desirable to have a measure of the performance of the model in predicting the roller loads, and the most convenient way to get this measure is to compare the model prediction with test results from the roller test facility. To avoid the complication of modeling an airdrop load such as a truck or tank, a 24-foot platform was loaded with dead weight loads and put on roller test facility to determine the roller loads. The distribution of the weights on the platform is shown in Figure 5. The nodal loads were computed by assigning the platform area equally among the nodes and the load assigned to each node is the portion of the dead weight loads covering its area. The data generation program includes the computation of the nodal loads based on this procedure and the data describing the particular load distribution shown in Figure 5 are contained in the file-element, ECS*ROLLER.DW—LOADS, which is added in the run stream of Appendix B. The weight of the platform was not included in this computation, so we should expect to see a difference between the model results and the test results of a little more than a thousand pounds, the weight of the platform.

The results from the 24-foot platform with dead weights on the roller load test facility are presented in Table 1 along with the prediction of the roller loads given by the model described above. The data in Table 1 are the roller loads in pounds and the table is arranged so that each row corresponds to a row of rollers across the aircraft; the columns correspond to proceeding longitudinally along the aircraft. The test results for rollers numbered 30 and 63 are blank because these rollers were not operating or supporting the load when the test was performed. The sum of the roller loads from the test is 26,446.5 pounds, and that from the model result is 25,274.5 pounds with the difference representing the platform weight which was not included in the model. The platform weight could, with relative ease, be added to the model, but here we are interested more with distribution of the roller loads than in magnitude, and it is not believed that this difference will influence the conclusion to be drawn regarding the model performance in predicting roller loads.

We begin by looking at the model predictions, and we notice that they behave as would be expected. The load is essentially uniform across the platform and each row of rollers shows a distribution indicative of this type of loading with the load on the two center rollers being nearly equal and that load being two to three times that on the outer rollers which are also nearly equal. As one looks along a column of Table 1 which corresponds to moving longitudinally along the aircraft or platform, the roller loads vary as they have ballast weights

BALLAST WEIGHT
DIMENSIONS: 24″x 48″
PLATFORM MODULE
DIMENSIONS: 47.9″x 104 .6″

BALLAST WEIGHT 25294 lb
PLATFORM WEIGHT 1013 lb
TOTAL 26307 lb

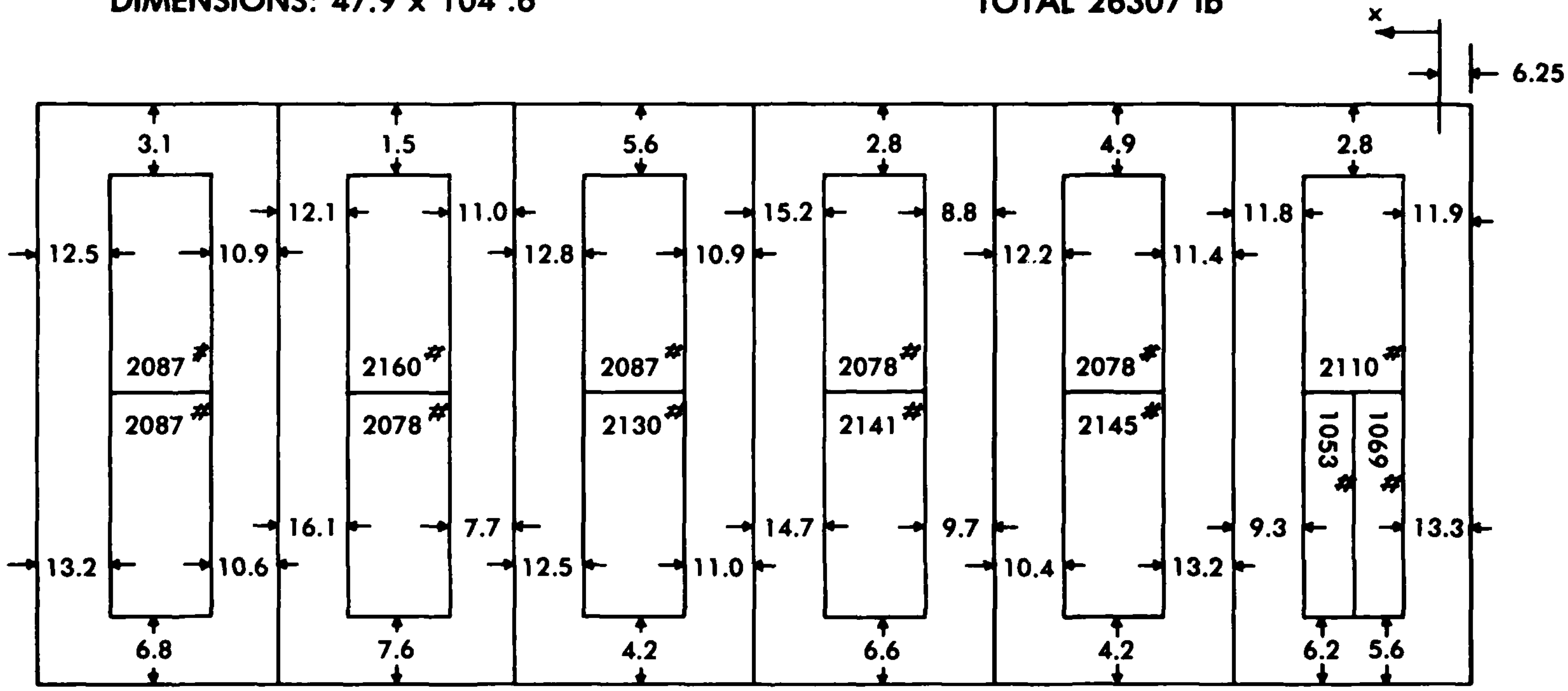


Figure 5. Distribution of ballast weight on the 24-foot platform

Table 1. Comparison of roller loads determined by the model with those from test.

No.	Model	Test	No.	Model	Test	No.	Model	Test	No.	Model	Test
1	38.6	0.0	30	129.5		59	145.4	14.0	88	63.1	0.0
2	137.4	307.3	31	416.2	44.1	60	447.9	109.2	89	190.6	386.4
3	164.0	594.3	32	499.7	785.9	61	500.9	643.3	90	213.5	526.4
4	112.4	228.9	33	343.9	686.7	62	315.5	0.0	91	136.6	354.9
5	63.8	3.5	34	142.1	0.0	63	132.4		92	39.6	485.1
6	83.3	14.0	35	231.1	218.4	64	279.0	454.3	93	95.8	0.0
7	161.4	652.4	36	453.4	3.5	65	453.9	198.1	94	155.5	0.0
8	176.7	23.8	37	488.5	133.7	66	461.4	228.9	95	158.7	40.6
9	118.8	23.8	38	373.4	267.4	67	309.2	471.1	96	106.4	430.5
10	89.4	37.1	39	158.1	440.3	68	156.9	768.6	97	91.3	16.8
11	113.3	214.9	40	344.9	123.2	69	353.0	348.6	98	139.5	167.3
12	145.0	140.0	41	495.7	205.1	70	482.9	478.1	99	186.7	16.8
13	118.8	163.8	42	405.2	150.5	71	374.6	567.0	100	147.4	14.0
14	60.0	519.4	43	189.5	47.6	72	175.1	476.7	101	68.9	365.4
15	48.5	78.4	44	150.7	266.0	73	146.0	191.1	102	54.3	119.7
16	100.0	18.9	45	372.2	214.9	74	366.7	257.6	103	109.2	310.8
17	141.5	252.0	46	516.4	303.8	75	505.6	331.1	104	152.1	3.5
18	120.5	296.8	47	420.4	260.4	76	405.9	177.8	105	127.3	7.0
19	76.5	196.7	48	196.7	287.0	77	183.6	515.9	106	77.3	7.0
20	78.0	0.0	49	291.7	423.5	78	220.4	214.9	107	83.8	143.5
21	120.8	0.0	50	465.3	512.4	79	435.8	406.7	108	177.9	136.5
22	120.0	0.0	51	460.9	652.4	80	492.7	214.9	109	215.0	99.4
23	68.9	2.8	52	226.2	314.3	81	320.3	365.4	110	151.5	37.8
24	42.4	102.9	53	83.8	380.1	82	120.7	58.1	111	82.4	515.9
25	63.1	123.2	54	262.7	416.5	83	263.3	269.5	112	100.3	331.1
26	133.2	65.1	55	471.9	338.1	84	473.6	424.9	113	183.3	98.7
27	145.0	37.8	56	488.9	116.2	85	494.1	553.7	114	196.9	58.1
28	79.8	0.0	57	254.2	430.5	86	263.5	199.5	115	111.0	6.3
29	6.1	2.8	58	42.4	230.3	87	46.2	474.6	116	11.3	0.0

directly over them or not. In comparing these predicted roller loads with those obtained from the test, we find disagreement; in fact, the two are not in agreement in any quantitative way. However, in a very general way the test results have the same trends in the distribution of roller loads in that the outer rollers generally have lower loads than the inner ones, and those directly under the ballast weights have higher loads. When the distribution of roller loads is examined in detail, there are some rather serious differences between the actual test results and the expected distribution. There are, for example, numerous unloaded rollers, some of them being center rollers. In the row of rollers consisting of rollers numbered 7, 36, 65 and 94 the left outer roller load is 652.4 pounds and the left inner roller load is 3.5 pounds. Such a combination of load is completely contrary to that expected for the type of loading present and in the context of the model described above. There are other examples but these illustrate the behavior found in the test and this behavior calls into question the assumptions of the model, in particular, the assumption of continual contact between platform and rollers made in modeling the platform-roller interaction. In the next section we look at another assumption for this interaction.

STATISTICAL MODEL

The results obtained with the deterministic model did not agree well with test results and the nature of the disagreement suggests that the model of the interaction between platform and the rollers was based on a poor assumption, that assumption being that the zero deflection positions of the rollers are coplanar and that the platform is always in contact with all the rollers.

The data suggest that a more accurate model would be based on the assumption that the number of rollers in contact with the platform is dependent on the magnitude of the load. This is caused by gaps between the unloaded platform and rollers due to waviness of the platform surface and unevenness in the roller heights. If, in the presence of such imperfection, an unloaded platform is set on the roller system, it will be supported by only a fraction of the rollers. As the load is placed on the platform, additional rollers will be loaded as the platform deflects. However, the rollers which initially support the unloaded platform and the loading sequence for the remaining rollers will be different for each platform and roller system combination. Since there are many platforms and rollers systems in use, it was felt that a statistical model of the platform-roller interaction was needed. Such a model complicates the analysis in two ways: first, a model describing the relationship between the rollers and the platform must be developed; and second, the model becomes nonlinear and must be solved incrementally. In this section of the report we describe such a model, its solution, and present some results given by the model.

Model Description

It should be recognized that this statistical model will be far more complex than the deterministic model, and because of this increased complexity we used an **ad hoc** platform structural model to expedite development of a computational algorithm during the initial phase of this work. This **ad hoc** model has some simplification, is smaller in size regarding number of degrees of freedom, it does not have any beams on the edges, and does not make use of NASTRAN. We have, however, tried to keep the general characteristics such as platform stiffness, platform width and roller spacing the same as the Type II platform-roller system. After first describing this **ad hoc** model, we will discuss integration of the NASTRAN platform structural model described above into the statistical model described in this section of the report.

Platform Model

The addition of the statistical description of the platform-roller interaction makes the problem nonlinear and requires several solutions for any loading case to obtain statistical significance. Both of these factors greatly increase the amount of computation required; thus, it seemed desirable in the development stages to treat smaller, less complex structural models than those described above for the deterministic case. In addition, the nonlinearity of the problem made the use of NASTRAN unattractive. As a result, it was decided to construct our own **ad hoc** platform model using the finite element described in reference 2. This is a rectangular plate bending element with three degrees of freedom, transverse deformation, and the two bending rotations at each of the four nodes. The element has isotropic stiffness properties and does not include transverse shear deformation. In debugging the program that used this finite element, we found that it contained an error as presented in reference 2. This error is in matrix element (2, 3) of submatrix $K_{11,1}$ or matric element (8, 3) of the complete stiffness matrix, and this element should be the negative of that given on page 30 of reference 2. An error became apparent when we found that the spectrum of the element stiffness contained only two eigen-values of value zero when three, one for each of the rigid body degrees of freedom, are expected. Correction of the error stated above resulted in the expected spectrum. The element was also used to solve the problem of the simply supported rectangular plate loaded at its center with a concentrated load. Satisfactory results were obtained from this solution which was compared with results from reference 3. With these checks on the finite element, we had confidence in it and used it to construct the platform model shown in Figure 6. Note that this model has the same geometry relative to platform width, node location, and roller spacing, and the platform stiffness is the same as that used in the NASTRAN plate elements. This model differs from the NASTRAN models described above in that it does not have any edge beams and it is shorter, resulting in a reduction in the size of the problem.

Roller Model

The roller model used here is no different from that used in the deterministic model. It consists of a simple scalar spring of stiffness measured experimentally and given previously. In the **ad hoc** model, all rollers were assumed to be directly under nodes, so there was no need to treat offset rollers.

[2] J. S. Przemieniecki; Theory of Matrix Structural Analysis; McGraw-Hill Book Co., New York; 1968.

[3] S. Timoshenko and S. Woinowsky-Kreiger; Theory of Plates and Shells; McGraw-Hill Book Co., New York; 1959.

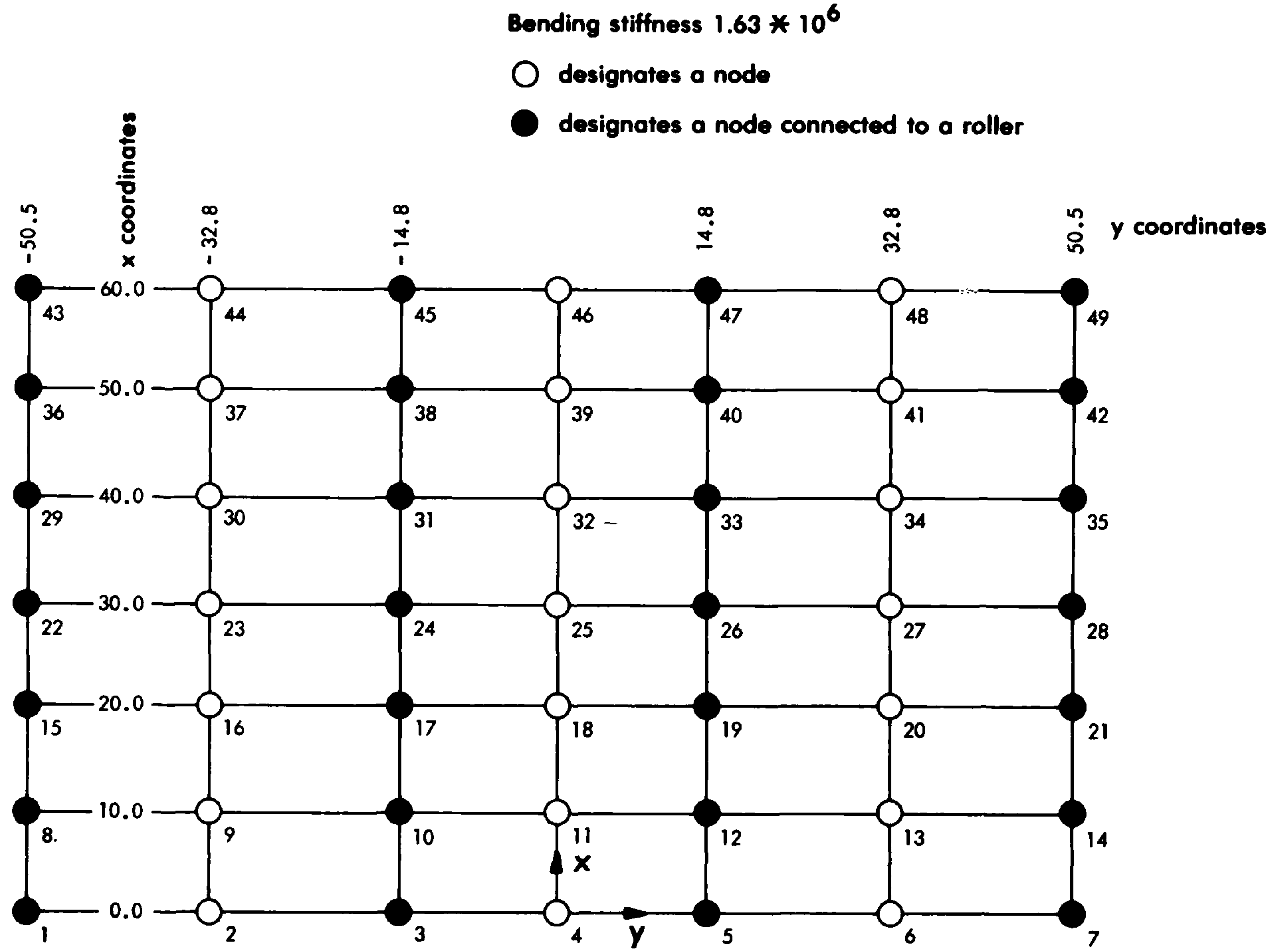


Figure 6. Platform finite element model for use in the statistical model

Platform-Roller Interaction and Solution Process

It is in the platform-roller interaction that the fundamental difference between the deterministic and statistical models appears. It should be recalled that, in the deterministic model, the platform and rollers were always in contact. Here, the number of rollers in contact with the platform depends on the magnitude of the load. The unloaded platform is assumed to sit on a specified number of rollers, n_i, with spaces or gaps between the remaining rollers and the platform. It is in the selection of the initial n_i rollers and the specification of the size of the gaps that the statistical nature of the model lies, and these parameters are chosen as follows. We obtain a set of n_r random numbers having a gamma distribution with specified mean and standard deviation. The gamma distribution is used because it will always give positive gaps. Each of the random numbers is paired with the integer name of one of the rollers resulting in an unordered array of random numbers and a corresponding array of ordered integers. The random numbers are then rearranged into ascending order with each number retaining its originally assigned roller association. This gives an ordered array of real numbers and a corresponding array of unordered integers. Since the real numbers are in ascending order, we set the first n_i of them to zero, and the rollers associated with these n_i numbers become the rollers on which the unloaded platform initially rests. The remaining $n_r - n_i$ random numbers are the gaps for the rollers with which they are associated. Given this model, the solution for the roller loads proceeds incrementally as follows: the stiffness matrix for the platform is computed and updated to include the rollers on which the unloaded platform initially rests. This linear problem is solved for the specified load. The displacements from this solution are compared with the gaps or spaces between the platform and the rollers not in contact with the platform to determine which roller will next contact the platform and what fraction of the load is required to cause contact to occur. Once this load fraction is known, the incremental displacements associated with all rollers and the incremental roller loads for the rollers in contact with platform are computed and saved as the total displacements and total roller loads. This completes the first increment and we proceed to the next by updating the stiffness matrix to account for the new roller that has come into contact with the platform. With the solution of this updated problem, we find a new load fraction; here, however, we must take into account the deformation of the platform over the rollers due to previous increments as well as the displacement of the current increment and the initial spaces between the platform and rollers. Given the new load fraction, the incremental roller loads and displacements are computed and used to update the total roller loads and displacements. After each increment, a check must be made to see if any rollers have been unloaded, since the rollers must be in compression or unloaded. If any roller is unloaded, a new load fraction which causes unloading to occur is computed and the total roller loads and displacements are again updated using this load fraction. The stiffness matrix is then updated either by removing a roller, if one has become unloaded, or by adding a roller for the next one to be contacted by the platform. This process then continues until either all the load is acting, at which point we have the total roller loads for the rollers in contact with the platform and perhaps some unloaded rollers, or until all rollers are in contact with the platform, in which case the final increment is assigned the load fraction required to apply all the remaining load. In either case, the result is the roller load distribution associated with the specified statistical model of the platform-roller interaction. Such a distribution is computed several times, as specified, and the statistics of the individual roller loads and the sum of the roller loads in each row of four are computed and printed as output. A FORTRAN program to carry out this computational process is presented in Appendix C.

Evaluation of the Model

The success of a statistical model such as the one described above depends on one's knowledge of the statistic of the gaps between the rollers and the platform. At present such knowledge is totally absent. Not only do we not know the statistical parameters of the gamma distribution used, but we do not even know if the gamma distribution is suitable for the representation of the phenomenon. Neither of these deficiencies represents a problem from a model-building or program point of view, since both the statistical model and/or the statistical parameters can be changed with ease and with no impact on the rest of the solution process. However, from the point of view of model evaluation, these deficiencies are crippling and no real evaluation can be made. The elimination of these deficiencies would require an extensive experimental program to measure the roller-platform gaps. Such an experimental program should include variations in aircraft and platforms in order to get meaningful data.

Regarding such data, observation of the platform used in the roller-load tests described here indicated a waviness in the platform that might best be described in terms of spectral quantities such as period and amplitude, with these spectral parameters being specified in a statistical fashion. Additionally, it appeared that the platform waviness was the most significant part of the imperfect matching in comparison to the unevenness of the rollers in the roller test facility. The unevenness of the rollers in an actual C–141 aircraft may present quite a different picture. Until such data are obtained, the statistical roller load model described here is incomplete, and little in the way of evaluation can be done.

In constructing this model, it became apparent that the magnitude of the roller stiffness was so large that, with the allowed loads, the rollers would undergo displacements on only one- or two-tenths of an inch. It is easy to believe that unevenness in the rollers or waviness in the platform of this order of magnitude exists, and thus that the occurrence of unloaded rollers is not only possible but likely. This suggests that making the rollers much more flexible would eliminate the occurrence of unloaded rollers and thus improve the distribution of load among the rollers. To demonstrate this we used the statistical model described above to run a series of calculations in which we varied the roller stiffness and looked at two measures of the load distribution, the maximum load, and the maximum sum of the load on the four rollers in a row. In these calculations we used a load of 10,000 pounds divided equally among all the nodes in the model and the statistical model used had a mean and standard deviation of 0.002; when the mean and standard deviation are equal, the gamma distribution reduces to the exponential distribution. The results of these calculations are shown in Table 2 where we present the mean and standard deviation of the maximum roller load and the maximum row-sum of roller loads. In addition, Table 2 also contains the mean and standard deviation of the differential maximum roller load and the differential maximum row-sum of roller loads. These differential quantities are computed by obtaining the difference between these parameters given by the statistical model and by a direct solution with all rollers in contact and the full load on the platform. Thus, the differential quantities are measures of departure from what might be called "the ideal situation." The statistics of these roller load parameters are based on twenty determinations of the roller load distribution with the statistical model. The results in Table 2 show that whenever statistical behavior is included, the maximum roller loads are greater than those occurring in the ideal case, but that the variation from the ideal decreases as the roller stiffness decreases. In fact, with the data in Table 2, it cannot be claimed in a statistical sense that the differential maximum row-sum of roller loads is nonzero when the

Table 2. Variation of Maximum Roller Loads With Roller Stiffness

Roller Stiffness, lb/in	Maximum Roller Load, lb: Total Mean	Total Std. Dev.	Differential Mean	Differential Std. Dev.
5,000	-400.622	1.86	-5.486	1.86
25,000	-451.240	10.91	-26.489	10.91
50,000	-479.083	14.41	-49.693	14.41
75,000	-506.005	26.92	-72.56	26.92
100,000	-519.157	20.72	-83.05	20.72
125,000	-557.971	43.86	-119.92	43.86
150,000	-553.227	54.84	-113.69	54.84

Roller Stiffness, lb/in	Maximum Row-Sum of Roller Loads, lb: Total Mean	Total Std. Dev.	Differential Mean	Differential Std. Dev.
5,000	-1453.10	3.47	-2.49	3.47
25,000	-1467.29	18.31	-27.94	18.31
50,000	-1495.60	27.89	-61.28	27.89
75,000	-1521.64	36.24	-88.11	36.24
100,000	-1525.77	34.39	-90.05	34.39
125,000	-1555.27	52.46	-117.80	52.46
150,000	-1545.86	37.03	-106.95	27.03

roller stiffness is 5,000. This is the result of the estimate of the mean being less than twice the standard deviation. It is, in fact, less than the standard deviation. Thus we see that as the roller stiffness decreases, the roller load distribution approaches the ideal. The maximum roller stiffness for which data are presented in Table 2 is approximately the stiffness of the rollers now in use, and this causes a 25% increase in the maximum load for the rather small imperfection of a 0.002 inch average gap between rollers and unloaded platform. It seems clear that more flexible rollers would be an improvement relative to the roller load distribution problem, since this decreases the magnitude of the maximum roller loads and makes the distribution of roller loads nearer the ideal distribution.

It seems appropriate to say a few words about the amount of computing required to get solutions from this statistical model. We begin by noting that this **ad hoc** model has 49 nodes with three degrees of freedom at each node for a total of 147 degrees of freedom. Thus for each increment in the solution a system of equations of order 147 must be solved. Of these 49 nodes in the model, 28 are associated with rollers. Of these 28 we have assumed in the calculation presented that eight are initially in contact with the platform, leaving 20 to be added incrementally, one on each increment. Typically, two or three additional increments are required because of unloading of rollers, so to get one sample set of roller loads, 22 increments are required. To obtain significant measures of the statistical behavior of the roller loads, we have been generating twenty samples, and these calculations take 85 minutes of central processor time. Thus, the amount of computer time even for this rather small model is rather large. The computing time can be reduced by generally cleaning up the computation process and also by carrying out a condensation of the platform structure before the incremental process is stated. This condensation would remove all the bending rotations and the transverse displacements not associated with rollers. For this **ad hoc** model such a condensation would reduce the problem of order 147 to a problem of order 28 and this would have a vast impact on the computation time. Now, what is of more interest is what this might tell us relative to computation for a statistical model with the NASTRAN platform models. These NASTRAN models have respectively 40, 56, 76, 96, 116, and 132 rollers on the 8, 12, 16, 20, 24, and 28-foot platforms, so that with condensations the order of the problems to be solved would be equal to the number of rollers plus one-half that many again to account for rotations needed for offset roller connections. It then appears that the **ad hoc** model with 147 degrees of freedom is near the higher limit of the NASTRAN models relative to the order of the problem to be solved. The other factor that affects computation time is the number of iterations required, and this depends on the number of rollers and the number of rollers initially in contact with the platform. Since the **ad hoc** model has 28 rollers with eight in contact initially, all the NASTRAN platform models will require more iterations than the **ad hoc** model. From these considerations, it appears that with the NASTRAN models the computing time might be significantly shorter with the small platforms and significantly larger with the large platforms than was experienced with the **ad hoc** model. This is all based on the assumption that the statistical model in which a small percent of the rollers are initially in contact with the platform is correct and, as we have stated above, we have not been able to evaluate this model. If it should be shown that a statistical model is one in which a large percent of the rollers are in contact initially, this would greatly reduce the computation time by reducing the number of iterations required for solution.

Integration of the NASTRAN platform models into the statistical solution is discussed in Appendix D.

CONCLUDING REMARKS

In a study of the mathematical modeling of the loads on C141 aircraft cargo rollers resulting from airdrop loads, two models were constructed: a deterministic model, and a statistical model. The deterministic model proved to be inadequate because it failed to represent the imperfection in the platform-roller interface. It is believed that this imperfection has a statistical character. To include this character, a statistical model was developed and tested successfully in a mathematical sense. However, because of lack of data, it was not possible to specify the statistical character of the interface, and thus the model could not be evaluated in the physical sense. Further data are needed to determine both the qualitative and the quantitative character of the platform-roller interface. The statistical model was used to show that the use of more flexible rollers would improve the roller load distribution by decreasing the significance of the imperfection relative to the deflections of the rollers.

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Table 3. Conversion table. US Customary units to SI units.

Quantity	US Customary	SI Units	To convert US Customary units to SI units multiply by
Mass	pounds mass	kilograms	0.455
Force	pounds force	newtons	4.45
Length	inch	meter	0.0254
	foot	meter	0.305
	yard	meter	0.91
Area	square inch	square meters	6.45×10^{-4}
	square foot	square meters	0.093
Volume	cubic inches	cubic meters	1.64×10^{-5}
	cubic feet	cubic meters	0.0283
Density	pounds per cubic inch	kilograms per cubic meter	2.77×10^{4}
	ounces	grams per square meter	34
Tension	pounds per inch	newtons per meter	176
Moment of Inertia	$(\text{inches})^4$	$(\text{meters})^4$	4.1×10^{-7}
Modulus of Elasticity and Stress	pounds per square inch	newtons per square meter	6.89×10^{3}

APPENDIX A

FORTRAN Program to Generate NASTRAN Bulk Data Deck

DATA-GEN

```
          COMPILER(DIAG=3)
          DIMENSION IXS(6),IXF(6),XT(164),YT(7)
          DIMENSION LLC(6),KKC(6),IROL(53),YROL(18)
          DIMENSION XT1(55),XT2(109)
          DIMENSION ZLOFSL(3),ZLOFSR(3),ZTOFSB(3),ZTOFST(3)
          DIMENSION QPLPR(5),QBPRL(5),QBPRT(5),QMAT1(4),QMAT2(4)
          EQUIVALENCE (XT1(1),XT(1)),(XT2(1),XT(56))
C
C   DEFINITION OF THE DATA ARRAYS
C        YT-  Y COORDINATES OF PLATFORM GRID POINTS
C        XT1+XT2=XT-  X COORDINATES OF PLATFORM GRID POINTS
C        IXS,IXF-  THE START AND FINISH LOCATIONS IN XT FOR
C             THE DIFFERENT LENGTH PLATFORMS
C        LLC-  STARTING POINTS IN IROL FOR DATA FOR DIFFERENT
C             LENGTH PLATFORMS
C        IROL-  POSITIVE VALUES DENOTE POSITION NUMBERS ALONG
C             LENGTH OF PLATFORM AT WHICH NODES ARE NOT CONNECTED
C             TO ROLLER SPRINGS   NEGATIVE VALUES DENOTE POSITIONS
C             WHERE CONNECTION TO ROLLER IS THRU AN OFFSET, REF BY LLC
C        YROL-  X OFFSETS BETWEEN GRID POINTS AND ROLLER SPRINGS
C             REF. BY KKC AND NEG.VALUES OF IROL
C        KKC-  STARTING POINTS IN YROL FOR DIFFERENT LENGTH PLATFORMS
C        ZLOFSOFFSETSFOR LONGITUDINAL BEAM BENDING AXIS
C             FROM NODAL AXIS
C        ZTOFS-  OFFSET FOR TRANSVERSE BEAM BENDING AXIS
C             FRON NODAL AXIS
C        QPLPR-  SECTION PROPEWTIES FOR PLATFORM PLATE
C        QBPRL-  SECTION PROPERTIES FOR LONGITUDINAL BEAM
C        QBPRT-  SECTION PROPERTIES FOR TRANSVERSE BEAM
C        ROLSTF & XOFS-   ROLLER STIFFNESS AND OFFSET AT
C             EDGE OF PLATFORM
C        QMAT1, QMAT2-   MATERIAL PROPERTIES FOR AL $ BALSA WOOD
          DATA IXS/1,13,32,56,86,122/
          DATA IXF/12,31,55,85,121,164/
          DATA  YT/-50.531,-32.8,-14.8,0.,14.8,32.8,
         .         50.531/
          DATA XT1/ -3.75 ,  0.   , 10.0  , 20.0  , 30.0  , 41.125,
         .         44.125, 50.0  , 60.0  , 70.0  , 80.0  , 89.0  ,
         .         -2.75 ,  0.0  , 10.0  , 20.0  , 30.0  , 40.0  ,
         .         42.125, 45.125, 50.0  , 60.0  , 70.0  , 80.0  ,
         .         90.0  , 93.0  ,100.0  ,110.0  ,120.0  ,130.0  ,
         .        138.875,
         .         -6.75 ,  0.0  , 10.0  , 20.0  , 30.0  , 38.125,
         .         41.125, 50.0  , 60.0  , 70.0  , 80.0  , 86.0  ,
         .         89.0  ,100.0  ,110.0  ,120.0  ,130.0  ,133.875,
         .        136.875,140.0  ,150.0  ,160.0  ,170.0  ,181.75 /
          DATA XT2/ -0.75 , 10.0  , 20.0  , 30.0  , 40.0  , 44.125,
         .         47.125, 50.0  , 60.0  , 70.0  , 80.0  , 92.0  ,
         .         95.0  ,100.0  ,110.0  ,120.0  ,130.0  ,139.875,
         .        142.875,150.0  ,160.0  ,170.0  ,180.0  ,187.75 ,
         .        190.75 ,200.0  ,210.0  ,220.0  ,230.0  ,235.625,
         .         -4.75 ,  0.0  , 10.0  , 20.0  , 30.0  , 40.125,
         .         43.125, 50.0  , 60.0  , 70.0  , 80.0  , 88.0  ,
         .         91.0  ,100.0  ,110.0  ,120.0  ,130.0  ,135.875,
         .        138.875,150.0  ,160.0  ,170.0  ,180.0  ,183.75 ,
         .        186.75 ,190.0  ,200.0  ,210.0  .220.0  ,231.625,
         .        234.625,240.0  ,250.0  ,260.0  ,270.0  ,279.5  ,
```

```
         .          -3.75 ,  0.0   , 10.0   , 20.0   , 30.0   , 41.125,
         .          44.125, 50.0   , 60.0   , 70.0   , 80.0   , 89.0   ,
         .          92.0  ,100.0   ,110.0   ,120.0   ,130.0   ,136.875,
         .         139.875,150.0   ,160.0   ,170.0   ,180.0   ,184.75 ,
         .         187.75 ,190.0   ,200.0   ,210.0   ,220.0   ,230.0   ,
         .         232.625,235.625,240.0   ,250.0   ,260.0   ,270.0   ,
         .         280.5  ,283.5   ,290.0   ,300.0   ,310.0   ,320.0   ,
         .         328.375/
          DATA LLC/1,5,10,18,28,40/
          DATA KKC/1,1,3,6,10,15/
          DATA IROL/  1, -6,  7,-12,  1,  7,  8, 14, 19,  1,  6,
         .            -7, 12,-13, 18, 19,-24, -1,  6,  7,-12, 13,-18,
         .            19, 24,-25, 30,  1, -6,  7, 12,-13, 18,-19, 24,
         .            25,-30, 31,-36,  1, -6,  7,-12, 13, 18,-19, 24,
         .            25, 31, 32,-37, 38, 43/
          DATA YROL/-1.125, 1.0  ,-1.125, 1.0  ,-1.75 , 0.75 ,
         .          -2.0    , 0.125,-0.75 ,-0.125,-1.0  , 1.125,
         .          -1.625, 0.5  ,-1.125, 1.0  , 0.125, 0.5  /
          DATA ZLOFSL,ZLOFSR/0.0,-1.795,-0.2648,0.0,1.795,-0.2648/
          DATA ZTOFSB,ZTOFST/-1.0525,0.0,0.0,1.0525,0.0,0.0/
          DATA QPLPR/0.163,2.5,0.0248,1.3,-1.3/
          DATA QBPRL/4.46,2.69,5.93,8.62,0.0/
          DATA QBPRT/0.6687,0.148,0.6683,0.8163,0.0/
          DATA ROLSTF,XOFS/3000.0,0.269/
          DATA QMAT1/10000000.0,4000000.0,0.33,0.098/
          DATA QMAT2/1.0,24900.0,0.1,0.006/
C
C          THE PARAMETER 'LENGTH' SPECIFIES PLATFORM LENGTH CONSIDERED
C
C                   LENGTH  1   2   3   4   5   6
C          PLATFORM LENGTH  8   12  16  20  24  28
C
C
C          GENERATION OF GRID CARDS    CONTAIN NODE NUMBER
C          AND NODAL COORDINATES IN THE IMPLIED GLOBAL
C          COORDINATE SYSTEM
C
C          JYN=THE NUMBER OF NODES IN THE Y DIRECTION, ACROSS THE
C              WIDTH OF THE PLATFORM
C
       10 FORMAT()
          WRITE(13,1012)
     1012 FORMAT('BEGIN BULK')
          READ(5,10) LENGTH
          IS=IXS(LENGTH)
          IF=IXF(LENGTH)
          JYN=7
          INODE=0
          Z=0.0
          JW=0
          DO 100  I=IS,IF
          X=XT(I)
          JW=JW+1
          JWT=JW
          JBEAM=0
          IF((I.EQ.IS).OR.(I.EQ.IF)) JBEAM=1
          IF((LENGTH.EQ.6).AND.(JW.GT.26)) JWT=JWT-1
```

```
            IF((LENGTH.EQ.2).AND.(JW.GT.2)) JWT=JWT-1
            JTEST=MOD(JWT,6)
            IF((JTEST.EQ.0).OR.(JTEST.EQ.1))JBEAM=1
            DO 100  J=1,JYN
            LBEAM=0
            IF((J.EQ.1).OR.(J.EQ.JYN)) LBEAM=1
            Y=YT(J)
            INODE=INODE + 1
            IF((JBEAM.EQ.1).OR.(LBEAM.EQ.1)) GO TO 128
            WRITE(13,1000) INODE,X,Y,Z
            GO TO 100
        128 WRITE(13,1014) INODE,X,Y,Z
        100 CONTINUE
       1000 FORMAT(' GRID',3X,I8,8X,3F8.3,13X,'126')
       1014 FORMAT(' GRID',3X,I8,8X,3F8.3)
      C
      C          GENERATION OF DUMMY GRID POINT CARDS FOR USE IN
      C          DEFINING BEAM LOCAL COOORDINATE SYSTEMS
      C                IGRID1 FOR LONGITUDINAL BEAMS ON LEFT
      C                IGRID2 FOR TRANSVERS BEAMS ON BOTTOM
      C                IGRID3 FOR LONGITUDINAL BEAMS ON RIGHT
      C                IGRID4 FOR TRANSVERSE BEAMS ON TOP
      C
            IGRID1=INODE + 1
            IGRID2=INODE +2
            IGRID3=INODE + 3
            IGRID4=INODE + 4
            X=350.0
            Y=100.0
            WRITE(13,1008)IGRID1,X,Y,Z
       1008 FORMAT(' GRID'3X,I8,8X,3F8.3,10X,'123456')
            X=-50.0
            WRITE(13,1008)IGRID2,X,Y,Z
            Y=-100.0
            WRITE(13,1008)IGRID3,X,Y,Z
            X=350.0
            WRITE(13,1008)IGRID4,X,Y,Z
      C
      C          GENERATION OF CQDPT CARDS FOR THE QUADRILATERAL BENDING
      C          ELEMENTS FOR THE PLATFORM MODEL
      C
            IELM=0
            IQP=IXF(LENGTH) - IXS(LENGTH)
            JYN1=JYN - 1
            DO 101  I=1,IQP
            DO 101  J=1,JYN1
            IW=I
            IF((LENGTH.EQ.6).AND.(I.GT.25))IW=IW-1
            IF((LENGTH.EQ.2).AND.(I.GT.1))IW=IW-1
            ISKIP=MOD(IW,6)
            IF(ISKIP.EQ.0) GO TO 101
            J1=J + (I-1)*JYN
            J2=J1+1
            J3=J1+JYN
            J4=J3+1
            IELM=IELM+1
            WRITE(13,1001) IELM,J1,J2,J4,J3
```

```
      101 CONTINUE
     1001 FORMAT(' CQDPLT ',I8,7X,'1',4I8,5X,'0.0')
C
C           GENERATION OF PROPERTY CARDS FOR CQDPLT PLATE ELEMENT
C
           WRITE(13,1002) QPLPR
     1002 FORMAT(' PQDPLT ',7X,'1',7X,'1',F8.3,7X,'2',4F8.3)
C
C           GENERATION OF MATERIAL PROPERTY CARD
C           QMAT1 & QMAT2 CONTAIN YOUNG'S MODULUS,SHEAR
C           MODULUS, POISSON'S RATIO AND MASS DENSITY
C
C              MATERIAL PROPERTY FOR BENDING,REF. ON PQDPLT
C
          WRITE(13,1003)QMAT1
     1003 FORMAT(' MAT1    ',7X,'1',2E8.2,2F8.3)
C              MATERIAL PROPERTY FOR TRANSVERSE SHEAR, REF.ON PQDPLT
C
          WRITE(13,1004) QMAT2
     1004 FORMAT(' MAT1    ',7X,'2',2E8.2,2F8.3)
C
C           GENERATION OF THE CBAR CARDS FOR THE BEAMS ALONG THE
C           PLATFORM EDGES
C
C                LONGITUDINAL BEAMS
C
          ICONT=100
          IQP1=IQP + 1
          DO 112  I=1,IQP
          JL1=JYN*(I-1) + 1
          JL2=JL1 + JYN
          JR1=JL1 + JYN - 1
          JR2=JR1 + JYN
          IPBARL=1
          IELM=IELM + 1
          ICONT=ICONT + 1
          WRITE(13,1009)IELM,IPBARL,JL1,JL2,IGRID1,ICONT,ICONT,ZLOFSL,ZLOFSL
          IELM=IELM + 1
          ICONT=ICONT + 1
          WRITE(13,1009)IELM,IPBARL,JR2,JR1,IGRID3,ICONT,ICONT,ZLOFSR,ZLOFSR
     1009 FORMAT(' CBAR',3X,5I8,23X,'2Q',J4/'+',J4,19X,6F8.3)
      112 CONTINUE
C
C                TRANSVERSE BEAMS
C
          LENP2=LENGTH + 2
          IPBART=2
          DO 113  I=1,LENP2
          INC=6
          MBEG=(I-1)*INC*JYN
          IF((LENGTH.EQ.6).AND.(I.GT.5)) MBEG=MBEG + JYN
          IF((LENGTH.EQ.2).AND.(I.GT.1)) MBEG=MBEG + JYN
          DO 113  J=1,JYN1
          MBEG=MBEG + 1
          JB1=MBEG
          JB2=JB1 + 1
          JT1=JB1 -JYN
```

```
      JT2=JT1 + 1
      IF(I.EQ.LENP2) GO TO 114
      IELM=IELM + 1
      ICONT=ICONT + 1
      WRITE(13,1009)IELM,IPBART,JB1,JB2,IGRID2,ICONT,ICONT,ZTOFSB,ZTOFSB
  114 CONTINUE
      IF(I.EQ.1) GO TO 115
      IELM=IELM + 1
      ICONT=ICONT + 1
      WRITE(13,1009)IELM,IPBART,JT2,JT1,IGRID4,ICONT,ICONT,ZTOFST,ZTOFST
  115 CONTINUE
  113 CONTINUE
C
C            GENERATION OF THE PBAR CARDS SPECIFYING THE BEAM
C            SECTION PROPRTIES, QBPRL & QBPRT CONTAIN AREA,
C            2 AREA MONENTS, TORSIONAL INERTIA AND NONSTRUCTURAL MASS
C
C
C                   FOR LONGITUDINAL BEAMS
C
      ID=1
      MID=1
      WRITE(13,1010)ID,MID,QBPRL
 1010 FORMAT(' PBAR',3X,2I8,5F8.3)
C
C                   FOR TRANSVERSE BEAMS
C
      ID=2
      WRITE(13,1010)ID,MID,QBPRT
C            GENERATION OF SCALAR SPRING ELEMENTS REPRESENTING THE
C            ROLLERS, THESE HERE ARE CONNECTING THE PLATFORM TO GROUND
C                ROLSTF=ROLLER STIFFNESS
C                XOFS=X OFFSET OF EDGE NODES FROM ROLLER CENTER LINE
C
      IZQ=0
      IF(IZQ.EQ.0)GO TO 778
      KC=KKC(LENGTH)
      LC=LLC(LENGTH)
      DO 106  I=1,IQP1
      YY=0.0
      INODE=(I-1)*JYN -1
      IF(I.NE.IROL(LC)) GO TO 102
      LC=LC + 1
      GO TO 106
  102 CONTINUE
      IF(I.EQ.IABS(IROL(LC))) GO TO 104
      GO TO 105
  104 YY=ABS(YROL(KC))
      LC=LC + 1
      KC=KC + 1
  105 CONTINUE
      DO 109  J=1,JYN,2
      XX=0.0
      IF(J.EQ.1) XX=XOFS
      IF(J.EQ.JYN) XX=XOFS
      INODE=INODE + 2
      ZKW=ROLSTF
```

```
      ZKPHX=ROLSTF*YY
      ZKPHY=ROLSTF*XX
      IELM=IELM + 1
      IDOF=3
      WRITE(13,1005) IELM,ZKW,INODE,IDOF
      IF(YY.EQ.0.0) GO TO 103
      IELM=IELM + 1
      IDOF=5
      WRITE(13,1005)IELM,ZKPHX,INODE,IDOF
  103 CONTINUE
      IF(XX.EQ.0.0) GO TO 109
      IELM=IELM + 1
      IDOF=4
      WRITE(13,1005) IELM,ZKPHY,INODE,IDOF
  109 CONTINUE
  106 CONTINUE
 1005 FORMAT(' CELAS2 ',I8,E8.3,2I8)
  778 CONTINUE
C
C           SINGLE POINT CONSTRAINTS TO FIX THE PLATFORM
C           IN ITS PLANE
C
      WRITE(13,1015)
 1015 FORMAT(' SPC1',10X,'1',6X,'12',7X,'1',7X,'7')
C
C           GENERATE MULTI-POINT CONSTRAINT CARDS THAT SIMULATE THE
C           JUNCTURE BETWEEN PLATFORM SECTIONS
C           BENDING ROTATIONS CONTINUOUS AT ALL NODES ALONG JOINT
C           TRANSVERSE DISPLACEMENT CONTINUOUS AT PLATFORM EDGES
C
      ISET=1
      DO 107  I=1,LENGTH
      INC=6
      NBEG=I*INC*JYN
      IF((LENGTH.EQ.6).AND.(I.GT.4))NBEG=NBEG + JYN
      IF((LENGTH.EQ.2).AND.(I.GE.1))NBEG=NBEG + JYN
      DO 107  J=1,JYN
      NBEG=NBEG + 1
      NBEGPJ=NBEG - JYN
      IF((J.EQ.1).OR.(J.EQ.JYN)) GO TO 110
      GO TO 111
  110 IDOF=3
      WRITE(13,1007)ISET,NBEG,IDOF,NBEGPJ,IDOF
  111 IDOF=4
      WRITE(13,1007)ISET,NBEG,IDOF,NBEGPJ,IDOF
      IDOF=5
  107 WRITE(13,1007)ISET,NBEG,IDOF,NBEGPJ,IDOF
 1007 FORMAT(' MPC',4X,3I8,5X,'1.0',2I8,4X,'-1.0')
C
C           GENERATION OF LOADING CARDS
C                 NODAL LOADS FOR DEAD WEIGHT LOADING TEST ON THE
C                 24 FOOT PLATFORM IN ROLLER TEST FACILITY
C
      FT=0.0
      READ(5,10) NLOAD
      IF(NLOAD.EQ.0) GO TO 129
      DO 117  ILOAD= 1,NLOAD
```

```
      WRITE(6,10) FTS
      READ(5,10)QLOAD,X1,X2,Y1,Y2
      FTS=0.0
      IX=IXS(LENGTH) - 1
      DO 118  I=1,IQP1
      NBEG=(I-1)*JYN
      IIX=IX + I
      IF(I.EQ.1) GO TO 119
      GX1=0.5*(XT(IIX) + XT(IIX-1))
      GO TO 120
  119 GX1=XT(IIX) - 1.5
  120 IF(I.EQ.IQP1) GO TO 121
      GX2=0.5*(XT(IIX) + XT(IIX+1))
      GO TO 122
  121 GX2=XT(IIX) + 1.5
  122 CONTINUE
      IF(GX2.LT.X1) GO TO 118
      IF((GX2.GE.X1).AND.(GX2.LE.X2).AND.(GX1.LE.X1)) XL=GX2-X1
       IF((GX2.GE.X2).AND.(GX1.LE.X1)) XL=X2-X1
      IF((GX2.LE.X2).AND.(GX1.GE.X1)) XL=GX2 - GX1
      IF((GX2.GE.X2).AND.(GX1.GE.X1).AND.(GX1.LE.X2)) XL=X2-GX1
      IF(GX1.GT.X2) GO TO 117
      DO 123  J=1,JYN
      NBEG=NBEG + 1
      IF(J.EQ.1) GO TO 124
      GY1=0.5*(YT(J) + YT(J-1))
      GO TO 125
  124 GY1=-52.281
  125 IF(J.EQ.JYN) GO TO126
      GY2=0.5*(YT(J) + YT(J+1))
      GO TO 127
  126 GY2=52.281
  127 CONTINUE
      IF(GY2.LT.Y1) GO TO 123
      IF((GY2.GE.Y1).AND.(GY2.LT.Y2).AND.(GY1.LT.Y1)) YL=GY2-Y1
      IF((GY2.LT.Y2).AND.(GY1.GT.Y1)) YL=GY2-GY1
      IF((GY2.GT.Y2).AND.(GY1.GT.Y1).AND.(GY1.LT.Y2)) YL=Y2-GY1
      IF(GY1.GT.Y2) GO TO 118
      FORCE=XL*YL*QLOAD
      ISET=1
      ICORD=0
      V1=0.0
      V2=0.0
      V3=1.0
      WRITE(13,1011)ISET,NBEG,ICORD,FORCE,V1,V2,V3
 1011 FORMAT(' FORCE  ',3I8,4F8.3)
      FT=FT + FORCE
      FTS=FTS + FORCE
  123 CONTINUE
  118 CONTINUE
  117 CONTINUE
      WRITE(6,10) FT
  129 WRITE(13,1013)
 1013 FORMAT('ENDDATA')
      STOP
      END
```

APPENDIX B

Procedure of Execution of Deterministic Model

APPENDIX B

Procedure of Execution of Deterministic Model

Presented here is the UNIVAC Exec VIII runstream for execution of the data generation program which yields the BULK DATA DECK in TPF$.DATA and the subsequent execution of NASTRAN. This is followed by the executive and case control deck for NASTRAN which is called by the runstream statement @ADD,P R. EX–CACONT. The final item is the data used by the data generation program to put the loads in the bulk data deck.

RUNSTREAM

```
@ASG,AX     ECS*ROLLER
@USE      R.,ECS*ROLLER
@ASG,T      13.
@FOR,S   R.DATA-GEN,DG
@XQT
1
@ADD,P   R.DW-LOADS
@ELT,I     TPF$.DATA
@ADD,P      13.
@FREE     13.
@QUAL     NASTRAN
@ASG,AX     NASTRAN*NASTRAN
@HDG,N
@XQT    NASTRAN*NASTRAN.L1NK1
NASTRAN  HICORE = 85000      CONFIG = 14     SYSTEM(34) = 2
@ADD,P   R.EX-CACONT
@ADD,P    TPF$.DATA
@ADD,P     NASTRAN*NASTRAN.NASTRAN
```

EXECUTIVE AND CASE CONTROL DECKS

```
ID          ROLLER,CHECK
APP          DISP
SOL           1,0
TIME           60
DIAG          22
CEND
TITLE        =   ROLLER LOAD SIMULATION
SUBSTITLE=   8 FT PLATFORM, DEAD WEIGHT LOADS
ELFORCE  =   ALL
STRESS     =   ALL
OLOAD      =   ALL
DISP         =   ALL
ECHO        =   BOTH
LOAD        =   1
MPC          =   1
SPC          =   1
```

===== CW-LOADS =====

```
  1.     13
  2.     1.856,7.05,19.05,-46.681,1.319
  3.     1.828,19.05,31.05,-46.081,1.919
  4.     1.832,5.65,29.65,1.919,49.919
  5.     1.862,54.82,78.82,-48.081,-0.081
  6.     1.804,53.02,77.02,-0.62,47.38
  7.     1.858,99.20,123.20,-45.62,2.38
  8.     1.804,98.30,122.30,1.42,49.42
  9.     1.849,148.88,172.88,-45.62,2.38
 10.     1.812,148.78,172.78,-1.382,46.618
 11.     1.804,192.95,216.95,-44.618,3.38
 12.     1.875,196.25,220.25,2.72,50.718
 13.     1.804,243.72,267.72,-45.418,2.582
 14.     1.812,244.02,268.02,1.12,49.12
```

APPENDIX C

Program for the Solution of the Statistical Model

APPENDIX C

Program for the Solution of the Statistical Model

The FORTAN computer program for solution of the statistical model consists of a main program called MAIN2 and this program uses six subroutines peculiar to it. Subroutine PLATE generates the platform finite element structural model and stores the stiffness matrix which is the embodiment of this model on file 3 in banded symmetric format. In carrying out this computation, the subroutine PFE3 is called from subroutine PLATE to generate the 12 x 12 element stiffness matrices. The subroutine WMTX is conditionally called by subroutine PLATE to print as output the element stiffness matrices generated by subroutine PFE3. These matrices are printed if the control parameter IPRINT has the value zero. Subroutine STGAP2 is called by the main program to generate a set of random numbers having a gamma distribution that are used to represent the spaces or gaps between the platform and rollers. These random numbers are paired with an integer which specifies the roller with which it will be associated. Once paired with these integers, the random numbers are placed in ascending order while retaining the originally paired integer. This ordering is accomplished by a call of subroutine AORDER from STGAP2. The load vector is generated by subroutine PLOAD which is called from the main program. The computation in PLOAD uniformly distributes the total load specified as input over all the nodes, both those associated with rollers and those not. In addition, the program uses three general purpose subroutines from the IMSL; GGAMT to generate the random numbers with a gamma distribution is called from STGAP2, LEQ1PB to solve the linear equations in band symmetric form, and BECORI to compute the statistics of the roller loads after all the incremental solutions have been completed. The subroutine GGAMT requires a starting seed number for which we use the time obtained by a call to the UNIVAC function ERTRAN.

The input to the program in the order read is as follows:

A	–	platform finite element length
B(1),B(2),B(3)	–	platform finite element widths
D	–	platform bending stiffness
XNU	–	Poisson's Ratio of platform material
P	–	total magnitude of the uniform load on the platform
ROLK	–	roller stiffness
IPRINT	–	print control parameter used in subroutine PLATE IPRINT = 0 Print element stiffness matrix IPRINT # 0 Do not print
NEL	–	number of elements in platform finite element model

NUMRO – number of rollers initially in contact with platform

NT – number of solutions for statistical accuracy

NR – number of rollers

GM,GSD – mean and standard deviation of the Gamma distribution associated with the roller-platform gaps

All of this input is read in free field format and an example of the input is presented as part of the runstream for execution of the program.

There are two sets of output for this program; one of which is an abbreviated set and is sent to logical unit 6, the standard FORTRAN print file. This output contains only a brief summary for each increment in the calculation containing the roller numbers in contact with the platform, the next roller to make contact, the load fraction, and the sums of the roller loads and the incremental roller loads. Following this output is a listing of the means and standard deviations of each of the roller loads and of the maximum roller load and maximum sum of rows of four roller loads. The other set of output contains details from each incremental solution including in addition to that in the summary output; a listing of rollers and their associated gaps; incremental solution vector; incremental roller displacements and loads; and total roller displacements and load. This detail output is sent to logical unit 7 which is a permanently assigned file. If the summary output reveals some difficulty in the computation process the detailed printout is then available for use in debugging.

A listing of the FORTAN source programs follows, and a UNIVAC Exec VIII runstream for execution of the program and a sample data set are also presented.

===== MAIN2 =====

```
            COMPILER(DIAG=3)
            DIMENSION NODE(50),GAP(50)
            DIMENSION IRONO(28),B(3),GK(147,27),BL(147,1)
            DIMENSION X(28),F(28),XINC(28),FINC(28)
            DIMENSION XT(28),FT(28),RLA(50,30)
            DATA IRONO/1,7,13,19,22,28,34,40,43,49,55,
                      61,64,70,76,82,85,91,97,103,106,
                      112,118,124,127,133,139,145/
      C
      C         READ DATA FOR PLATE GEOMETRY AND STIFFNESS
      C         A&B(K) ELEMENT LENGTHS AND WIDTHS
      C         D&XNU PLATE STIFFNESS AND POISSON'S RATIO
      C         NEL NUMBER OF ELEMENTS
      C         P LOAD MAGNITUDE
      C         NUMRO NUMBER OF ROLLERS
      C         ROLK ROLLER STIFFNESS CONSTANT
      C         IRONO ARRAY DEFINING THE RELATION BETWEEN
      C               ROLLER NO. AND THEIR DOF NUMBER
      C               IRONO(I)=THE DOF NO.FOR THE ROLLER I
      C
            READ(5,10)A,B,D,XNU,P,ROLK
            READ(5,10)IPRINT,NEL,NUMRO
            READ(5,10)NT,NR,GM,GSD
            WRITE(6,23)A,B,D,XNU,NEL,ROLK,P
            WRITE(7,23)A,B,D,XNU,NEL,ROLK,P
         23 FORMAT(1H1,//2X,'ELEMENT LENGTH',F10.5/
           .         2X,'ELEMENT WIDTHS',3F10.5/
           .         2X,'STIFFNESS',E15.5/
           .         2X,'POISSONS RATIO',F10.5/
           .          2X,'NO. OF PLATE ELEMENTS',I5/
           .         2X,'ROLLER STIFFNESS',E15.5/
           .         2X,'LOAD',E15.5)
      C
      C         GENERATE UNCONSTRAINED GLOBAL STIFFNESS MATRIX
      C
            CALL PLATE(A,B,D,XNU,NEL,IPRINT)
         10 FORMAT()
      C
      C         NT=NUMBER OF TESTS OR REPITITIONNS TO BE MADE
      C            TO OBTAIN STATISTICAL SIGNIFICANCE
      C         NR=NUMBER OF ROLLERS SUPPORTING PLATFORM
      C         GM=MEAN OF THE ROLLER-PLATFORM GAPS
      C         GSD=STANDARD DEVIATION OF THE ROLLER-PLATFORM GAPS
      C         NUMRO=NO. OF ROLLERS INITIALLY IN CONTACT
      C               WITH THE PLATFORM
      C
            WRITE(6,20)NR,GM,GSD,NT,NUMRO
            WRITE(7,20)NR,GM,GSD,NT,NUMRO
         20 FORMAT(//2X,'NO. OF ROLLERS',I5/
           .       2X,'ROLLER GAP MEAN',E15.5/
           .       2X,'ROLLER GAP STD.DEV.',E15.5/
           .       2X,'NO. OF TESTS',I5/
           .       2X,'NO. OF ROLLERS INITIALLY IN CONTACT',I5)
      C
      C         BEGIN A LOOP ON THE NUMBER OF REPETITIONS OR
      C         TESTS.  GET NODEE NUMBERS FOR ROLLERS ON WHICH
      C         THE PLATFORM INITIALLY SETS
```

```
          NNT=0
          DO 100  IR=1,NT
          WRITE(6,26)IR
          WRITE(7,26)IR
       26 FORMAT(1H1,//2X,'BEGINNING OF TEST OR REPETITION',I4)
          NNT=NNT + 1
C
C              NNT RELATES TO THE NUMBER OF TESTS OR
C              REPETITIONS- WHEN STIFFNESS MATRIX IS
C               FOUND SINGULAR NNT IS DECREASED SO
C               SO IT IS THE TRUE NO. OF TESTS
C
          KEY=0
          CALL STGAP2(NODE,GAP,NR,GM,GSD )
          DO 135  NZ=1,NUMRO
      135 GAP(NZ)=0.0
          WRITE(6,19)
          WRITE(7,19)
       19 FORMAT(//2X,'ROLLER NOS. & GAPS')
          WRITE(6,12)(NODE(IP),GAP(IP),IP=1,NR)
          WRITE(7,12)(NODE(IP),GAP(IP),IP=1,NR)
       12 FORMAT(2X,I5,E12.5)
C
C               INITIALIZE PARAMETERS FOR INCREMENTAL SOLUTION
C
          INCNUM=0
          INCNO=0
          SFRAC=0.0
          DO 110  K=1,NR
          X(K)=0.0
      110 F(K)=0.0
          NRC=NUMRO
      109 CALL PLOAD(BL,P,49)
          INCNUM=INCNUM + 1
          INCNO=INCNO + 1
          WRITE(6,27)INCNUM
          WRITE(7,27)INCNUM
       27 FORMAT(1H1,//2X,'BEGINNING OF INCREMENT',I4)
          REWIND 3
          READ(3,2001)((GK(IP,JP),IP=1,147),JP=1,27)
     2001 FORMAT(2X,6E20.12)
          DO 101  I=1,NRC
          L=NODE(I)
          LL=IRONO(L)
      101 GK(LL,27)=GK(LL,27) + ROLK
C
C               OBTAIN SOLUTION
C
          CALL LEQ1PB(GK,147,26,147,BL,147,1,5,Z1,Z2,IER)
          WRITE(7,10)IER
          WRITE(6,33)
          WRITE(7,33)
       33 FORMAT(//2X,'ROLLERS IN CONTACT FOR THIS INCREMENT')
          WRITE(6,34)(NODE(IP),IP=1,NRC)
          WRITE(7,34)(NODE(IP),IP=1,NRC)
       34 FORMAT(8I5)
          IF(IER.EQ.0) GO TO 111
```

===== MAIN2 =====

```
            FT(IX)=0.0
            XT(IX)=0.0
            XINC(IX)=0.0
        120 FINC(IX)=0.0
            KC=0
            RL=0.0
            RLINC=0.0
            FMAX=0.0
            DO 105  J=1,NR
            L=NODE(J)
            LL=IRONO(L)
            XINC(L)=FRAC*BL(LL,1)
            XT(L)=X(L) + XINC(L)
            IF(J.GE.NRC) GO TO 106
            FINC(L)=-FRAC*BL(LL,1)*ROLK
            FT(L)=F(L) + FINC(L)
            RL=RL + FT(L)
            RLINC=RLINC + FINC(L)
      C
      C              CHECK TO SEE IF INCREMENT HAS CAUSED
      C              ROLLER UNLOADING, IF UNLOADIN OCCURS COMPUTE
      C              SMALLEST LOAD FRACTION TO CAUSE ZERO
      C              LOAD ON AN UNLOADED ROLLER
      C
            IF(FT(L).LE.FMAX) GO TO 106
            UFRAC=-F(L)/(BL(LL,1)*ROLK)
            KC=KC + 1
            IF(KC.EQ.1) GO TO 122
            IF(UFRAC.GE.UTEM)GO TO 106
        122 UTEM=UFRAC
            JUNL=J
            LUNL=L
            KEY=1
        106 CONTINUE
        105 CONTINUE
            UFRAC=UTEM
      C
      C              ADJUSTMENT OF MODEL FOR ROLLER UNLOADING
      C
            IF(KEY.EQ.0) GO TO 121
            IF(INCNO.GT.1)GO TO 124
      C
      C              ROLLER UNLOADED ON FIRST INCREMENT, INTERCHANGE
      C              UNLOADED ROLLER, AN INITIAL ROLLER, WITH NEXT
      C              ROLLER TO BE CONTACTED AND REPEAT FIRST INCREMENT
      C
            INCNO=INCNO - 1
            NODE(JSAV)=LUNL
            NODE(JUNL)=ISAV
            NRC=NRC-1
            SFRAC=SFRAC-FRAC
            WRITE(6,35) LUNL,ISAV
            WRITE(7,35) LUNL,ISAV
         35 FORMAT(//2X,'ROLLER UNLOADED ON FIRST INCREMENT'/
           .         2X,'INTERCHANGE ROLLERS',I4,' AND',I4)
            WRITE(7,19)
            WRITE(7,12)(NODE(IP),GAP(IP),IP=1,NR)
```

***** MAIN2 *****

```
              NNT=NNT - 1
              GO TO 100
          111 CONTINUE
              WRITE(7,14)
           14 FORMAT(///2X,'SOLUTION VECTOR')
              DO 115  IW =1,49
              IWW=(IW-1)*3
          115 WRITE(7,13)IW,BL(IWW+1,1),BL(IWW+2,1),BL(IWW+3,1)
           13 FORMAT(2X,I4,3E15.6)
      C
      C            COMPUTE LOAD FRACTION FOR CURRENT INCREMENT
      C
              NRC=NRC+1
              IF(NRC.GT.NR)GO TO 116
              TEM=100.0
              DO 102  I=NRC,NR
              L=NODE(I)
              LL=IRONO(L)
              IF(L.LT.0) GO TO 104
              IF(BL(LL,1).LE.0.0)GO TO 104
              FRAC=(GAP(I)-X(L))/BL(LL,1)
              IF(I.EQ.NRC) GO TO 103
              IF(FRAC.GE.TEM) GO TO 104
          103 TEM=FRAC
              ISAV=L
              JSAV=I
          104 CONTINUE
          102 CONTINUE
              FRAC=TEM
              SFRT=SFRAC
              SFRAC=SFRAC + FRAC
              IF(SFRAC.LE.1.0) GO TO 107
              FRAC=1.0 - SFRT
              SFRAC=1.0
              GO TO 107
          116 FRAC=1.0-SFRAC
              SFRAC=1.0
              WRITE(6,28)FRAC,SFRAC
              WRITE(7,28)FRAC,SFRAC
           28 FORMAT(//2X,'FINAL INCREMENT'/
             .          2X,'INCREMENTAL LOAD FRACTION',E15.5/
             .          2X,'TOTAL LOAD FRACTION',E15.5)
          107 CONTINUE
              SFRT=SFRAC
              WRITE(6,22) ISAV,FRAC,SFRAC
              WRITE(7,22) ISAV,FRAC,SFRAC
           22 FORMAT(//2X,'NEXT NODE TO CONTACT',I5/
             .          2X,'INCREMENTAL LOAD FRACTION',E15.6/
             .          2X,'TOTAL LOAD FRACTION',E15.6)
              IF(KEY.EQ.0) GO TO 129
              IF(KEY.EQ.2) NODE(JUNL)=-NODE(JUNL)
              KEY=0
          129 CONTINUE
      C
      C            UPDATE DEFLECTION AND ROLLER LOADS
      C
              DO 120  IX=1,NR
```

```
      KEY=0
      GO TO 109
  124 CONTINUE
      IF(LUNL.NE.LROLA) GO TO 128
      NODE(JUNL)=-NODE(JUNL)
      NRC=NRC-1
      SFRAC=SFRAC - FRAC
      WRITE(6,36)INCNUM,LUNL,LUNL
      WRITE(7,36)INCNUM,LUNL,LUNL
   36 FORMAT(//2X,'ON INCREMENT',I4,' ROLLER',I4,' WAS UNLOADED'/
                2X,'THIS INCREMENT NEGLECTED AND ROLLER',I4,'WILL NOT'/
                2X,'BE CONSIDERED IN NEXT INCREMENT')
      WRITE(7,19)
      WRITE(7,12)(NODE(IP),GAP(IP),IP=1,NR)
      KEY=2
      GO TO 109
  128 CONTINUE
      SFRAC=SFRAC - FRAC + UFRAC
      DO 130  IU=1,NR
      XINC(IU)=0.0
      FINC(IU)=0.0
      FT(IU)=0.0
  130 XT(IU)=0.0
      RL=0.0
      RLINC=0.0
      DO 131  J=1,NR
      L=NODE(J)
      LL=IRONO(L)
      XINC(L)=UFRAC*BL(LL,1)
      XT(L)=X(L) + XINC(L)
      IF(J.GE.NRC)GO TO 132
      FINC(L)=-UFRAC*BL(LL,1)*ROLK
      FT(L)=F(L) + FINC(L)
      RL=RL + F(L)
      RLINC=RLINC + FINC(L)
  132 CONTINUE
  131 CONTINUE
      WRITE(6,37)INCNUM,LUNL
      WRITE(7,37)INCNUM,LUNL
      GAPTEM=GAP(JUNL)
      DO 133  JJ=JUNL,NRC
      NODE(JJ)=NODE(JJ+1)
  133 GAP(JJ)=GAP(JJ+1)
      NODE(NRC+1)=NODE(JUNL)
      GAP(NRC+1)=GAP(JUNL)
      NRC=NRC - 2
   37 FORMAT(//2X,'ON INCREMENT NO.',I4,' ROLLER NO.',I4,' WAS'/
     .          2X,'UNLOADED, LOAD FRACTION TO UNLOAD ROLLER'/
     .          2X,'APPLIED TO DISPLACEMENTS AND LOADS AND'/
     .          2X,'UNLOADED ROLLER REMOVED FRON MODEL')
      WRITE(7,19)
      WRITE(7,12)(NODE(IP),GAP(IP),IP=1,NR)
  121 CONTINUE
      DO 123  IA=1,NR
      X(IA)=XT(IA)
  123 F(IA)=FT(IA)
      WRITE(7,21)
```

===== PLATE =====

```
      COMPILER(DIAG=3)
      SUBROUTINE PLATE(A,B,D,XNU,NEL,IPRINT)
      DIMENSION EK(12,12,3),GK(147,27),INODE(4)
      DIMENSION B(3),HEAD(2)
C
C           GENERATE ELEMENT STIFFNESS MARTIX AND
C           GLOBAL STIFFNESS MATRIX
C
C
C           READ DATA FOR GENERATION OF ELEMENT
C           STIFFNESS MATRIX
C
      ICK=0
   10 FORMAT()
      DO 199  K=1,3
      CALL PFE(A,B(K),D,XNU,EK(1,1,K))
      DO 198  I=1,12
      JB=I + 1
      DO 198  J=JB,12
  198 EK(I,J,K)=EK(J,I,K)
      IF(IPRINT.EQ.0)CALL WMTX(EK(1,1,K),12,12,HEAD,12)
  199 CONTINUE
 2000 FORMAT(/1X,6E15.6)
C
C           SUCCESSIVELY ADD THE ELEMENT STIFFNESS MATRIX
C           INTO THE GLOBAL STIFFNESS MATRIX
C           DO LOOP ON THE ELEMENT NUMBERS
      NUMR=147
      NUMC=27
      IBW=NUMC
      LAD=0
      DO 100 IEL=1,NEL
C
C           GENERATE INDEX FOR SELECTION OF ELEMENT
C           STIFFNESS MATRIX
C
      KELM=MOD(IEL,6)
      IF(KELM.LE.3)KSEL=KELM
      IF(KELM.EQ.4)KSEL=3
      IF(KELM.EQ.5)KSEL=2
      IF(KELM.EQ.0)KSEL=1
C
C           GENERATE ELEMENT NODE NUMBERS FROM ELEMENT NOS.
C
      INODE(1)=IEL+LAD
      INODE(2)=INODE(1) + 1
      INODE(3)=INODE(2) + 7
      INODE(4)=INODE(1) + 7
      L=MOD(IEL,6)
      IF((L.EQ.0).AND.(IEL.NE.1))LAD=LAD+1
C
C           START DOUBLE NESTED DO LOOP ON THE NODES OF
C           THE PLATE ELEMENT OR ON THE 3X3 PARTITIONS
C           OF THE ELEMENT STIFFNESS MATRIX
      DO 101  I=1,4
      DO 102  J=1,4
C
```

```
***** PLATE *****
C           JJB AND IIB ARE THE BEGINING COLUMN AND ROW
C           INDICES IN THE ELEMENT STIFFNESS MATRIX
C           JB AND IB ARE THE BEGINNING COLUMN AND ROW
C           INDICES IN THE GLOBAL STIFFNESS MATRIX
C
          JB=(INODE(J) - 1)*3
          IB=(INODE(I) - 1)*3
          JJB=(J-1)*3
          IIB=(I-1)*3
C
C           DOUBLE NESTED DO LOOP IN A 3X3 PARTITION OF
C           THE ELEMENT STIFFNESS MATRIX
C
          DO 103  II=1,3
          DO 104  JJ=1,3
C
C           THE FOLLOWING FORTRAN STATEMENT WOULD ADD THE
C           THE ELEMENT MATRIX TO THE GLOBAL MATRIX IF
C           WE WERE USING FULL SYMMETRIC STORAGE
C           GK(IB+II,JB+JJ)=GK(IB+II,JB+JJ)+EK(IIB+II,JJB+JJ,KSEL)
C
C          HERE WE USE BAND SYMMETRIC STORAGE FOR WHICH
C           THE ROW INDEX RETAINS ITS TRUE VALUE. A COLUMN
C           IN THE BAND SYMMETRIC STORAGE REPRESENTS A
C           CO-DIAGONAL AND ALONG A CO-DIAGONAL THE DIFFERENCE
C           BETWEEN THE ROW INDEX AND THE COLUMN INDEX IS
C           CONSTANT AND IS USED AS THE COLUMN INDEX IN THE
C           BAND SYMMETRIC STORAGE. THE COLUMN INDEX IS EQUAL TO
C           THE BANDWIDTH  MINUS THE DIFFERENCE IN THE ROW AND
C           COLUMN INDICES.
C           IR AND IC ARE THE ROW AND COLUMN INDICES OF THE
C           GLOBAL STIFFNESS MATRIX IN BAND SYMMETRIC STORAGE
C
          IR=IB+II
          IC=JB + JJ
          IF(IR.LT.IC) GO TO 104
          IRR=IR
          ICC=IBW - (IR - IC)
      181 GK(IRR,ICC)=GK(IRR,ICC) + EK(IIB+II,JJB+JJ,KSEL)
      104 CONTINUE
      103 CONTINUE
      102 CONTINUE
      101 CONTINUE
      100 CONTINUE
          WRITE(3,2001)((GK(IP,JP),IP=1,147),JP=1,27)
     2001 FORMAT(2X,6E20.12)
          RETURN
          END
```

===== PFE3 =====

```
      SUBROUTINE PFE(A,B,D,XNU,EK)
C          GENERATE PLATE FINITE ELEMENT STIFFNESS
C          MATRIX
C          A,B=PLATE WIDTH AND LENGTH
C          D,XNU=PLATE STIFFNESS AND POISSION RATIO
C
      DIMENSION EK(12,12)
      C=A/B
      C=C*C
      U=1.0/C
      AS=A*A
      BS=B*B
      AB=A*B
      D1=1.0 +5*XNU
      T3=1.0/35.0
      T2=1.0/25.0
      EK(1,1)=156*T3*(C + U) + 72*T2
      EK(4,4)=EK(1,1)
      EK(7,7)=EK(1,1)
      EK(10,10)=EK(1,1)
      EK(2,2)=(4*T3*C + 52*T3*U + 8*T2)*BS
      EK(5,5)=EK(2,2)
      EK(8,8)=EK(2,2)
      EK(11,11)=EK(2,2)
      EK(3,3)=(52*T3*C + 4*T3*U + 8*T2)*AS
      EK(6,6)=EK(3,3)
      EK(9,9)=EK(3,3)
      EK(12,12)=EK(3,3)
      EK(2,1)=(22*T3*C + 78*T3*U + 6*T2*D1)*B
      EK(5,4)=-EK(2,1)
      EK(8,7)=-EK(2,1)
      EK(11,10)=EK(2,1)
      EK(3,1)=-(78*T3*C + 22*T3*U + 6*T2*D1)*A
      EK(6,4)=EK(3,1)
      EK(9,7)=-EK(3,1)
      EK(12,10)=-EK(3,1)
      EK(3,2)=-(11*T3*(C + U) + 0.5*T2*(1.0+60*XNU))*AB
      EK(6,5)=-EK(3,2)
      EK(9,8)=EK(3,2)
      EK(12,11)=-EK(3,2)
      EK(4,1)=54*T3*C - 156*T3*U - 72*T2
      EK(10,7)=EK(4,1)
      EK(4,2)=(13*T3*C - 78*T3*U - 6*T2)*B
      EK(5,1)=-EK(4,2)
      EK(10,8)=-EK(4,2)
      EK(11,7)=EK(4,2)
      EK(4,3)=(-27*T3*C + 22*T3*U + 6*T2*D1)*A
      EK(6,1)=EK(4,3)
      EK(10,9)=-EK(4,3)
      EK(12,7)=-EK(4,3)
      EK(5,3)=(13*0.5*T3*C - 11*T3*U -0.5*T2*D1)*AB
      EK(6,2)=-EK(5,3)
      EK(11,9)=EK(5,3)
      EK(12,8)=-EK(5,3)
      EK(5,2)=(-3*T3*C + 26*T3*U - 2*T2)*BS
      EK(11,8)=EK(5,2)
      EK(6,3)=(18*T3*C - 4*T3*U - 8*T2)*AS
```

***** PFE3 *****

```
      EK(12,9)=EK(6,3)
       EK(7,1)=-54*T3*(C + U) + 72*T2
       EK(10,4)=EK(7,1)
      EK(8,1)=(13*T3*C + 27*T3*U - 6*T2)*B
      EK(11,4)=-EK(8,1)
      EK(7,2)=-EK(8,1)
      EK(10,5)=EK(8,1)
      EK(9,1)=(-27*T3*C - 13*T3*U + 6*T2)*A
      EK(12,4)=EK(9,1)
      EK(7,3)=-EK(9,1)
      EK(10,6)=-EK(9,1)
      EK(8,2)=(3*T3*C + 9*T3*U + 2*T2)*BS
      EK(11,5)=EK(8,2)
      EK(9,3)=(9*T3*C + 3*T3*U + 2*T2)*AS
      EK(12,6)=EK(9,3)
      EK(9,2)=(-13*0.5*T3*(C + U) +0.5*T2)*AB
      EK(8,3)=+EK(9,2)
      EK(12,5)=-EK(9,2)
      EK(11,6)=-EK(9,2)
      EK(10,1)=-156*T3*C + 54*T3*U - 72*T2
      EK(7,4)=EK(10,1)
      EK(11,1)=(-22*T3*C + 27*T3*U - 6*T2*D1)*B
      EK(10,2)=EK(11,1)
      EK(8,4)=-EK(11,1)
      EK(7,5)=-EK(11,1)
      EK(12,1)=(-78*T3*C + 13*T3*U - 6*T2)*A
      EK(10,3)=-EK(12,1)
      EK(9,4)=EK(12,1)
      EK(7,6)=-EK(12,1)
      EK(11,2)=(-4*T3*C + 18*T3*U - 8*T2)*BS
      EK(8,5)=EK(11,2)
      EK(12,2)=(-11*T3*C + 13*0.5*T3*U - 0.5*T2*D1)*AB
      EK(11,3)=-EK(12,2)
      EK(9,5)=-EK(12,2)
      EK(8,6)=EK(12,2)
      EK(12,3)=(26*T3*C - 3*T3*U - 2*T2)*AS
      EK(9,6)=EK(12,3)
      DO 100  I=1,12
      DO 100  J=1,I
  100 EK(I,J)=EK(I,J)*D/AB
      RETURN
      END
```

***** WRITEMATRIX *****

```
      SUBROUTINE WMTX(A,NR,NC,HEAD,NMAX)
      DIMENSION A(NMAX,NMAX),HEAD(2)
      PRINT 202,HEAD
      KE=0
      KSET=NC/8
      KLEFT=MOD(NC,8)
      IF(KLEFT.NE.0)KSET=KSET+1
      DO 1 KT=1,KSET
      KB=KE+1
      KE=KE+8
      IF(KT.EQ.KSET)KE=NC
      PRINT 200,(J,J=KB,KE)
      DO 1 I=1,NR
    1 PRINT 201,I,(A(I,J),J=KB,KE)
  200 FORMAT(//1X,10HROW     COL,I4,7(10XI4))
  201 FORMAT(1X,I4,8E14.6)
  202 FORMAT(////1X,2A6,1X,6HMATRIX)
      RETURN
      END
```

***** STSGAP2 *****

```
      SUBROUTINE STGAP2(NODE,G,L,GM,GSD)
C          COMPUTE THE GAP SIZES BETWEEN THE ROLLERS
C          AND THE PLATFORM AS A SET OF RANDOMLY
C          DISTRIBUTED NUMBERS OF MEAN=GM AND
C          STANDARD DEVIATION=GSD.  THERE ARE TO BE
C           L OF THESE GAP SIZES IN THE ARRAY G.
C          THESE GAP SIZES WILL HAVE A GAMMA DISTRIBUTION.
C          THE GAP SIZES ARE ARRANGED IN ASCENDING ORDER
C          IN ARRAY G AND THE CORRESPONDIN ROLLER NUMBERS
C          ARE IN ARRAY NODE.
C          L=NUMBER OF ROLLERS
C
      DIMENSION G(1),NODE(1),WK(3)
      DOUBLE PRECISION DSEED
      LM3=L
      CALL ERTRAN(9,IR1,IR2)
      DECODE(6,13,IR2)JR
   13 FORMAT(I6)
      DSEED=JR
      VAR=GSD*GSD
      B=VAR/GM
      A=GM*GM/VAR
      WK(1)=0.0
      CALL GGAMT(DSEED,A,B,LM3,WK,G)
      DO 1  I=1,LM3
    1 NODE(I)=I
      CALL AORDER(G,NODE,LM3)
      RETURN
      END
```

===== AORDER =====

```
      SUBROUTINE AORDER(A,IA,N)
      DIMENSION A(N),IA(N)
      LIM=N-1
  100 INT=1
      DO 101 I=1,LIM
      IF(A(I+1).GE.A(I)) GO TO 101
      TEMP=A(I+1)
      ITEM=IA(I+1)
      A(I+1)=A(I)
      IA(I+1)=IA(I)
      A(I)=TEMP
      IA(I)=ITEM
      INT=I
  101 CONTINUE
      IF(INT.EQ.1) GO TO 102
      LIM=INT-1
      GO TO 100
  102 CONTINUE
      RETURN
      END
```

===== PLOAD =====

```
      SUBROUTINE PLOAD(BL,P,NUMRO)
      DIMENSION BL(147,1)
C
C           P IS TAKEN AS THE TOTAL LOAD SO
C           P/NUMRO IS THE LOAD PER ROLLER
C
      F=P/NUMRO
      DO 100  I=1,NUMRO
      IP=I*3 - 2
  100 BL(IP,1)=F
      RETURN
      END
```

===== (ROLLER) STST/RUNST =====

```
@ASG,AX  ECS*QRINT.
@USE  Q.,ECS*QRINT.
@BRKPT  PRINT$/Q
@PRT,S  ECS*ROLLER.STST/RUNST
@USE  R.,ECS*ROLLER.
@ASG,T  3.
@ASG,AX  ECS*OUTPUT.
@USE  7.,ECS*OUTPUT.
@FOR,S  R.MAIN2,M
@MAP,IS  A,B
  IN  M
  IN  R.
 LIB  DAO*IMSL.
 END
@XQT  B
10.0,17.7,18.0,14.8,1630000.0,0.3,10000.0,150000.0
1,36,8
10,28,0.002,0.002
@BRKPT  PRINT$
```

APPENDIX D

Integration of the NASTRAN Platform Models with the Statistical Model

APPENDIX D

Integration of the NASTRAN Platform Models with the Statistical Model

The statistical model described in this report is incomplete in that it is missing the description of the platform-roller interaction. Should data be obtained to resolve this knowledge gap, it would be desirable to integrate the NASTRAN platform structural models with the program for carrying out the solution of the statistical model described in Appendix C. To carry this out two areas of activity are required: modification of the solution algorithm MAIN2 given in Appendix C, and obtaining the platform stiffness matrix from NASTRAN. The first of these areas is straightforward programming and would include expanding the size of the arrays, changing the input, changes to account for the rollers that are offset from nodes in the NASTRAN models and the addition of an out-of-core equation solver to handle the increased problem size. The second area of activity, obtaining the platform stiffness matrices from NASTRAN, would also seem straightforward but in the attempts made as a part of this work it turned out not to be. The NASTRAN documentation describes auxiliary subroutines for the output of data such as stiffness matrices and procedures to alter the rigid formats to include these subroutines. However, the subroutine that appeared to provide the most direct means for doing this, OUTPUT2, did not work properly either in trying to write information on an assigned file or to the punch file. The alternative technique used was to insert the subroutine MATPRN in the static analysis rigid format to print the stiffness matrix as part of the printed output file. To get around having to repunch too large a quantity of data back into the *machine, we break pointed the print file to a permanently assigned file. After the execution* of NASTRAN this permanelty assigned file could be edited to obtain the stiffness matrix in the format dictated by the subroutine MATPRN. This matrix could, however, be read in this format and converted to storage in the banded symmetric format required by program MAIN2 for solution of the statistical model. It is the platform stiffness matrix without the attachment of any springs simulating rollers that is desired, so it is necessary to modify the generation of the bulk data deck so the scalar spring elements are not included. This process has been completely carried out for the 8-foot platform and has been read into a modified version of MAIN2. However, debugging of the modified version has not been completed.